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## REVIEW – META-ANALYSIS

# The plausible effects of wearing face masks on sports performance – A scoping review

*Les effets plausibles du port de masques faciaux sur les performances sportives – Une analyse des connaissances*

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## KEYWORDS

COVID-19;  
Exercise;  
Face mask;  
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## Summary

**Objectives.** – The objectives of this scoping review are to discuss, firstly, the positive aspects of wearing face masks during training (such as a barrier to COVID-19 transmission, air pollutant exposure, and adding load on respiratory resistance flow); secondly, the negative aspects (adverse effects on body temperature and hypoxia risks); and thirdly, the training responses of wearing face masks on aerobic and anaerobic performance.

**News.** – Besides social distancing and hand hygiene, wearing a face mask is proposed to be the prime advocacy for virus containment. During the period of high risk of contamination, the return to sport guidelines proposed by international and national sport federations included wearing face masks during training sessions. However, it is necessary to discuss the pros and cons of wearing face masks during exercise.

**Prospects.** – Although it was essential to wear a face mask during exercise or sport-specific training, there is conflicting evidence on the implications of the use of face masks on physical, physiological as well as psychological well-being or performance. Based on the conflicting empirical findings and anecdotal evidence, certain recommendations have been made for adequate use of face masks during exercise; both to break the chain of transmission and prevent the physiological compromise expected from wearing face masks during exercise. The present review can help stakeholders balance sport guidelines in the event of a respiratory virus pandemic with athlete safety.

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**MOTS CLÉS**  
COVID-19 ;  
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Entraînement  
physique

**Conclusion.** – Conflicting evidence of mechanistic links between the dose of exercise and the possible adverse effects associated with exercising with face masks is available. Adequately powered studies with strong methodological quality on appropriate selection of masks and usage based on the intensity, duration, and type of sport, age, and gender is needed now for the stakeholders to make informed decisions with respect to exercising with face masks.  
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**Résumé**

**Objectifs.** – Les objectifs de cette revue des connaissances sont de discuter, premièrement, les aspects positifs du port de masques pendant l'entraînement (comme une barrière à la transmission du COVID-19, l'exposition aux polluants atmosphériques et l'ajout de charge sur le flux de résistance respiratoire) ; deuxièmement, les aspects négatifs (effets indésirables sur la température corporelle et risques d'hypoxie) ; et troisièmement, les conséquences du port de masques faciaux à l'entraînement sur les performances aérobies et anaérobies.

**Nouvelles connaissances.** – Outre la distanciation physique et l'hygiène des mains, le port d'un masque facial est proposé comme le principal plaidoyer pour la maîtrise des contaminations par le nouveau coronavirus. Pendant la période à haut risque de contamination, les directives de retour au sport proposées par les fédérations sportives internationales et nationales incluaient le port de masques lors des séances d'entraînement. Cependant, il est nécessaire de discuter les avantages et les inconvénients du port de masques faciaux pendant l'exercice.

**Perspectives.** – Bien qu'il fut essentiel de porter un masque facial pendant l'exercice ou l'entraînement spécifique au sport, il existe des preuves contradictoires sur les implications des masques faciaux sur les performances physiques, physiologiques, et le bien-être psychologique. Sur la base des résultats contradictoires et de données empiriques, certaines recommandations ont été faites pour une utilisation optimale de masques faciaux pendant l'exercice, à la fois pour briser la chaîne de transmission du virus et éviter le compromis physiologique attendu du port des masques faciaux pendant l'exercice. La présente revue peut aider les parties prenantes à trouver un équilibre entre les directives sportives en cas de pandémie par un virus respiratoire et la sécurité des athlètes.

**Conclusion.** – Il existe des données contradictoires sur les liens mécanistiques entre la dose d'exercice et les effets indésirables possibles associés à l'exercice avec des masques faciaux. Des études de qualité au plan méthodologique, sur la sélection des masques, leur utilisation en fonction de l'intensité, de la durée et du type de sport, de l'âge et du sexe des sportifs sont nécessaires pour que les parties prenantes puissent prendre des décisions éclairées en ce qui concerne l'exercice avec des masques faciaux.

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## 1. Introduction

World Health Organization and the global health agencies advocate hand hygiene, face covering and social distancing to ameliorate the chances of harboring the Coronavirus and curbing the raging pandemic. Rapid inhalation during sporting activities may increase concentration of aerosols or particulate matter deeper within self [1], whereas sneezing or coughing may provide the opportunity of virus contact with other sportsmen. Hence, masks could act as a protective gear against virus during sports training sessions.

Masks may be viewed as therapeutic against particulate matter, inducing flow resistance thus proposed to imitate a high altitude training effect on  $\dot{V}O_2$  and humidity thus aiding in curbing exercise induced bronchospasms [2]. However, few experimental trials have contradictory votes against face masks during moderate to heavy workloads. Fikenzier et al. (2020) investigated the effects of surgical masks and N95 face masks on cardiorespiratory parameters during

incremental exercise tests. N95 face masks reduced arteriovenous oxygen difference by approximately 16.7% and maximal oxygen consumption by 14% though stroke volume, and cardiac output did not differ [3]. Furthermore, competitive asymptomatic athletes may not be advised to wear a mask as a preventive measure for COVID-19, since it may not significantly reduce the infection [4]. The inconsistent evidence regarding exercising wearing face masks has created a sense of ambiguity in the minds of athletes and sporting organizations which has resulted in non-compliance to the use of facemasks during exercise and this in turn could continue to perpetuate the virus transmission.

The objectives of this scoping review are to discuss, firstly, the positive aspects of wearing face masks during training (such as a barrier to COVID-19 transmission, air pollutant exposure, and adding load on respiratory resistance flow); secondly, the negative aspects (adverse effects on body temperature and hypoxia risks); and thirdly, the recommendations of wearing face masks during the exercise.

## 2. Methods

### 2.1. Search criteria and databases

Three databases have been searched from inception until 5th January 2021. A panel of five experts, including a sports physician and a sports physiotherapist who were not involved in this review, directed the keywords. Combinations of "face mask" OR "masks" AND "exercise" OR "training" OR "sports" were used to screen for potentially relevant studies focused on face mask use. The primary author with the help of institutional librarian executed the search.

### 2.2. Eligibility criteria

The potential studies that investigated the effects of face mask, face covering during exercise, training or any type of physical activity in human volunteers were included. Studies, published in languages apart from English, were excluded. Two independent reviewers (AD and SF) included the potential articles after title and abstract screening. The disagreement between two reviewers was resolved through mutual consensus. If found relevant, full text articles were downloaded and the necessary data were extracted as described below.

### 2.3. Data extraction

The following information (author, year, objective of the study, study participants, procedure, key findings, and recommendation) was included in the data extraction sheet ([Table 1](#)). The primary author extracted the above data and mapped the potential physiological mechanisms with the face mask during exercise.

## 3. Results

The results of the present review is reported based on preferred reporting items for systematic reviews and meta-analyses for scoping reviews (PRISMA-ScR, 2018). A total of 1591 studies addressing effects of wearing face masks during exercise or training were initially identified from PubMed ( $n=565$ ), Scopus ( $n=684$ ) and Web of Science ( $n=342$ ). The summary of the literature selection process is shown in [Fig. 1](#) and the characteristics of the included studies ( $n = 10$ ) are shown in [Table 1](#). The results are presented as a narrative synthesis.

Our scoping review elaborates the physiological, and psychological mechanisms that underpin wearing of face masks during sport or exercise performance.

### 3.1. Positive aspects of wearing face masks during exercise

#### 3.1.1. Face masks prevent transmission of viruses

During training or competition, athletes are usually in close proximity to one another, which would allow the micro-droplets to travel from one player to the other via any of the mechanisms mentioned earlier. Contemporary evidence claims that masks have protective value against various

infectious agents [14–16]. The use of face masks has been suggested as a strategy in order to limit community transmission via asymptomatic individuals as well as clinically undetected carriers [17,18], who could be a major driver for the transmission of COVID-19 [19]. Empirical evidence suggests that masks may have the potential to protect the wearer from acquiring various infections as well as prevent them from transmitting the infection [14,20]. Wearing a surgical mask or reusable elastomeric respirator, payload of viruses during inhalation can be cut down to 20–30% or less than 5%, respectively, with a lower propensity of getting infected [21]. Non-medical masks are still markedly superior when compared to no mask usage when outdoors and while training [17]. Thus, during the COVID-19 pandemic, the use of face masks by athletes during training could prevent the spread of respiratory droplets and could protect them from the novel coronavirus infection [22].

#### 3.1.2. Face masks reduce exposure to air-pollutants

Potential adverse consequences of short- and long-term exposure to air pollutants (like carbon, nitrogen, and sulfur dioxides, black carbon, ozone, and particulate matter) during training and performance include oxidative damage and inflammation in the airways and vascular system, bronchoconstriction followed by decreased lung function and exacerbation of asthma [23–27]. Studies have also suggested that air pollution exposure impairs regulation of the autonomic nervous system, reduces heart rate variability, and increases blood pressure [28–30]. Previous research showed that with every  $10 \mu\text{g}/\text{m}^3$  increase in  $\text{PM}_{10}$ , FVC was decreased by 3.14% [31], and performance of women marathon runners was decreased by 1.4% [27]. Ultrafine and fine particulate matter ( $\text{PM}_2.5$ ) inhalation decreases exercise performance as well [24]. These physiological mechanisms could negatively affect the sporting performance.

Individuals wearing a face mask when exposed to air-pollutants for 24 hours showed significantly lesser symptoms of irritation in the nose and throat, better blood flow and oxygen delivery to the heart, less tiredness compared to the control group not wearing a face mask [32]. A randomized crossover trial on young adults in China also showed wearing particulate-filtering respirators may produce cardiovascular benefits by improving autonomic nervous function and reducing blood pressure [33], which corroborate with the findings of Langrish et al. (2009) [34]. Although the literature regarding the ability of face masks to prevent or lessen the negative health effects caused by exposure to air pollution in the athletic population is limited, the potential benefits could still be extrapolated and implemented for athletes. Those athletes targeting to excel in major competitions should consider the use of a face mask as a beneficial sports gear during training to abrogate the adverse effects of air pollution.

#### 3.1.3. Face masks reduce risk of exercise-induced asthma

Cold and dry air inhalation can trigger the risk of exercise-induced asthma (EIA) in athletes including winter sports athletes [35]. Investigations demonstrated that EIA could be prevented by inspiration of warm and humidified air during exercise. Previous studies have found that face masks act as

**Table 1** Evidence demonstrating physiological consequences while exercising with face mask, a mandate during COVID-19 pandemic.

Author (Year)	Country	Objective of the study	Study design	Participants	Procedure	Key findings	Recommendations given
Fikenzer et al. (2020) [3]	Germany	Effect of surgical and FFP2/N95 masks on pulmonary and cardiac capacity in healthy adults	Randomized single blind crossover study	Active and healthy male ( $n=12$ )	Three incremental exertion tests without mask, with surgical mask, and with N95 mask	<ul style="list-style-type: none"> <li>Marked discomfort wearing the masks</li> <li>Increased breathing resistance</li> <li>Masks significantly reduces lung function at rest (FVC, FEV1, PEF) and at maximum load (VE, BF, TV)</li> <li>N95 masks show more negative effects compared to surgical masks</li> </ul>	<ul style="list-style-type: none"> <li>Cardiorespiratory effects have to be considered versus the potential protective effects of face masks on viral transmissions.</li> <li>The quantitative data may, therefore, inform medical recommendations and policy makers</li> </ul>
Epstein et al. (2020) [5]	Israel	Physiological effects of wearing surgical masks and N95 respirators during short-term strenuous workout	Multiple cross-over trial	Healthy young adult male ( $n=16$ )	Maximal exercise test without a mask, with a surgical mask, and with an N95 respirator	<ul style="list-style-type: none"> <li>Short-term moderate-strenuous aerobic physical activity with a mask is associated with only minor changes in physiological parameters and mild increase in <math>\text{EtCO}_2</math></li> </ul>	<ul style="list-style-type: none"> <li>Subjects suffering from lung and heart diseases should have a cautious evaluation before attempting physical activity with any mask</li> </ul>
Shaw et al. (2020) [6]	Canada	Exercise performance is impaired by wearing face masks	Randomized, counter-balanced cross-over design	14 participants (men, $n=7$ ; and women, $n=7$ )	Progressive cycle ergometer exercise while wearing a cloth face mask, surgical mask, or no mask	<ul style="list-style-type: none"> <li>Wearing face masks during vigorous exercise had no discernible detrimental effect on performance, arterial oxygen saturation or muscle oxygenation</li> </ul>	<ul style="list-style-type: none"> <li>Exercise should be encouraged for everyone during Covid-19 to reduce many of the risk factors</li> </ul>
Lässing et al. (2020) [7]	Germany	Effects of medical face masks on cardiopulmonary parameters during constant-load exercise	Prospective randomized crossover study	Healthy men ( $n=14$ )	Two constant load tests at maximal lactate steady state workload with and without masks	<ul style="list-style-type: none"> <li>Surgical masks increase airway resistance and heart rate during steady state exercise</li> <li>Endurance performance and perceived stress remained unchanged</li> </ul>	<ul style="list-style-type: none"> <li>Further studies in the elderly and in persons with pulmonary or cardiac diseases are necessary</li> </ul>

Table 1 (Continued)

Author (Year)	Country	Objective of the study	Study design	Participants	Procedure	Key findings	Recommendations given
Wong et al. (2020) [8]	China	Risk of virus transmission during a football match	Observational study	Male professional football players ( <i>n</i> = 4)	Video analysis of an entire football match	•Average of 52 episodes of infection-risky behaviors per 90 min	•Minimizing human-to-human contact and practicing proper personal hygiene. •Athletes' on-field own risky behaviors should be avoided to minimize unnecessary infection
		Physiological effect of wearing a face mask during exercise	Repeated measures laboratory based study	Healthy male ( <i>n</i> = 10) and female ( <i>n</i> = 13)	Graded treadmill walking at 4 km/h for 6 min with and without wearing a surgical mask EtCO <sub>2</sub> and SpO <sub>2</sub> while wearing the masks in rest and during exercise (6 kg weight dumbbell lifting and 20 deep knee-bends)	•Wearing facemask significantly elevates heart rate and perceived exertion	•Adjust the exercise intensity when masked
Germonpre et al. (2020) [9]	Belgium	Protection level offered and the risk of CO <sub>2</sub> accumulation while wearing snorkel masks	Observational study	—	—	•Small initial increase in EtCO <sub>2</sub> , but remained within physiological limits	•Proper selection of mask size, fit testing, quality, and choice of filter are important.
Chandrasekaran et al. (2020) [10]	India	Physiological responses while exercising with face masks	Hypothetical review	27 articles exploring the effects of face masks reviewed	A hypothetical mapping was performed linking masking with the altered physiological variables	Exercising with face masks: •increases anaerobic metabolism, and cardiac load •decreases cognition, muscle metabolism, immune cell motility, GFR and coronary perfusion	•Low to moderate-intensity exercise, rather than vigorous exercise wearing face mask •People with chronic diseases to exercise at home without the use of face masks

Table 1 (Continued)

Author (Year)	Country	Objective of the study	Study design	Participants	Procedure	Key findings	Recommendations given
Lee et al. (2020) [11]	China	Physiological mechanisms of ventricular tachycardia/ventricular fibrillation leading to sudden cardiac death	Hypothetical review	42 articles	A hypothetical mapping was performed linking masking with altered coronary variables	Exercise with face masks may increase: •risk of SCD •adrenergic stimulation and oxidative stress •acute and/or intermittent hypoxia and hypercapnia	•Avoid face mask during high intensity exercise •With masks, exercise intensity should remain low to avoid precipitation of lethal arrhythmias
Freemas et al. (2019) [12]	USA	Respiratory physiology variables between a mouthpiece and face mask during high-intensity exercise	Randomized trial	Men ( <i>n</i> =14)	Performed 6 min of cycle ergometry at 90% of $\dot{V}O_{2\text{peak}}$ with a mouthpiece or a face mask	•No significant differences in ventilation, breathing mechanics, or ratings of perceived breathlessness between the masks during high-intensity exercise	•Face mask can be used as a more comfortable alternative during high-intensity exercise than mouthpiece
Roberge et al. (2010) [13]	USA	Physiological impact of the N95 FFR on healthcare workers	Repeated measures study	Healthcare workers women ( <i>n</i> =7) and men ( <i>n</i> =3)	One-hour treadmill walking at 1.7 miles/h and 2.5 miles/h wearing N95 FFR with and without exhalation valve, and without FFR	•No significant physiological burden and exertion with FFRs at low intensity work. •No significant difference in moisture retention between FFR with and without exhalation valve	•Higher cost of FFR with valve may not be warranted in a low work rate scenario. •Further studies are required for longer period with different FFR

EtCO<sub>2</sub>: end tidal carbon dioxide; FVC: forced vital capacity; FEV<sub>1</sub>: forced expiratory volume in 1 second; FFR: filtering face piece respirator; PEF: peak expiratory flow; VE: minute ventilation; BF: breathing frequency; TV: tidal volume; SpO<sub>2</sub>: oxygen saturation; SCD: sudden cardiac death.

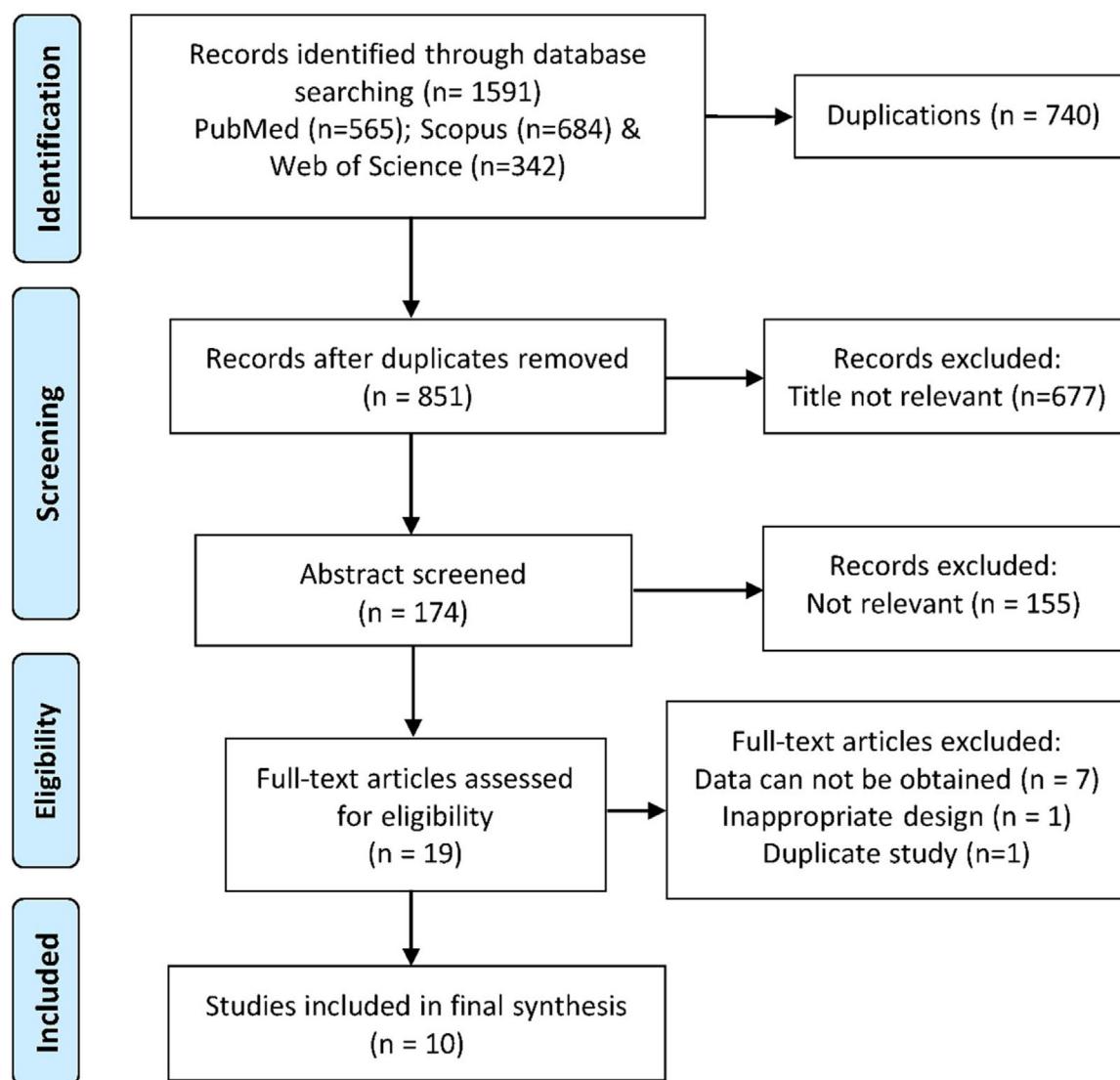


Figure 1 Flow diagram for the inclusion of potential studies.

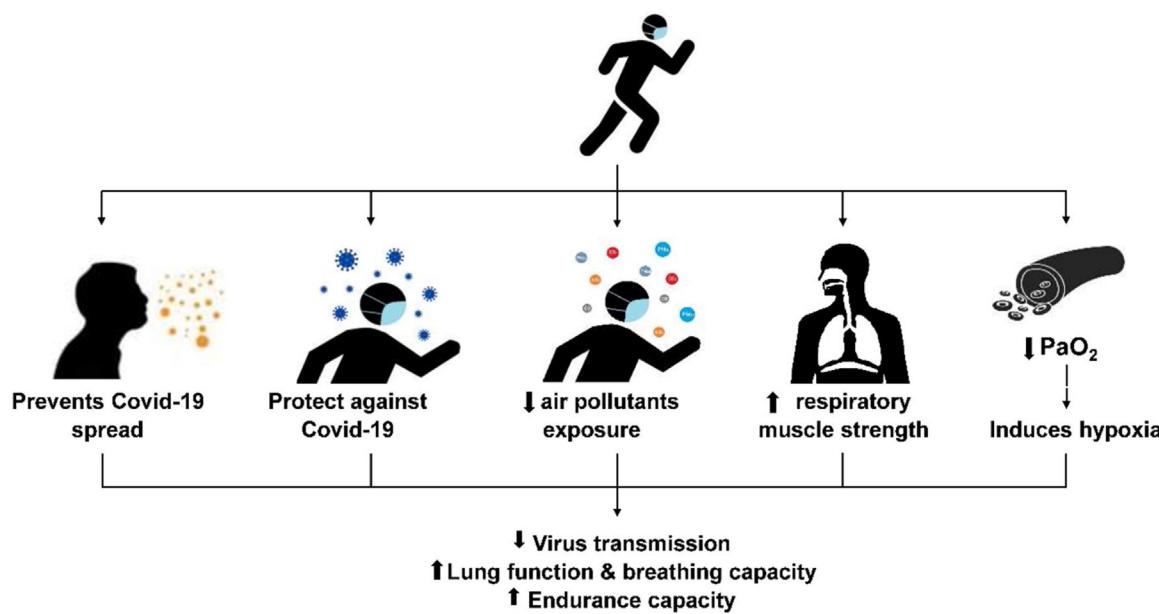
an inexpensive, non-pharmacologic alternatives that offer effective protection against exercise/cold-induced asthma [36,37]. The face mask also induces a continuous positive airway pressure (CPAP) and has been found to be beneficial for patients with chronic obstructive pulmonary disease (COPD), asthma [36–38], and COVID-19 as well [39]. CPAP increases functional residual capacity (FRC), widens the gap between FRC and closing volume (CV), followed by reduced likelihood of airway closure [40]. However, effects of CPAP on athletic performance are still scanty, but it can be speculated that during this COVID-19 pandemic, athletes exercising with a face mask may gain a potential advantage in attenuating EIA.

### 3.1.4. Face masks may increase respiratory muscle strength

Face masks appear to add flow resistance to the respiratory muscles during inhalation by limiting air supply. Thus, in turn, training with facemasks may strengthen the muscles of

respiration specifically to improve cardiorespiratory fitness, thus leading to better sports performance [41]. This is especially relevant to elite athletes, where the pulmonary system may become a limiting factor. Lee et al. (2011) reported a mean increment of 126 and 122% in inspiratory and expiratory flow resistances, respectively, with the use of N95 respirators [42]. However, the mechanisms behind these improvements are not well understood and need further research.

During exercise at higher intensities, athletes might encounter higher expiratory flow rates. This high flow rate may shift the 'equal pressure points' to distal airways causing early alveolar and bronchiolar closing volumes thus reducing the gas exchange (Fig. 2). This effect may exacerbate the respiratory complications in athletes with underlying lung hypersensitivity. Cloth masks worn during exercise may provide 'resistance' to higher airflow, which may reverse the shift of equal pressure points back to the proximal airways thus preventing the early alveolar collapse [43]. Therefore, masks may be prophylactic in preventing



**Figure 2** Possible benefits of wearing a face mask during training.

alveolar collapse at high expiratory flow rates and providing auto-PEEP to the distal airways in exercising athletes.

### 3.1.5. Face masks may provide hypoxemia-induced benefits

The concept of hypoxemia-induced benefits in athletes wearing a face mask came around with the commercial product 'elevation training mask', originally designed to simulate altitude training. Research suggests that the elevation training mask induces modest hypoxemia, and low oxygen level in our blood [44]. The use of masks in a resting situation decreases the availability of  $O_2$  by ~14% and increases aspirated  $CO_2$  level by 30 times. Short exercise bouts performed at an intensity of 6 to 8 METS with masks decreases  $O_2$  by 3.7% and increases the  $CO_2$  concentration by 20% [45]. However, it is unclear if the decrease in  $O_2$  is due to the use of a face mask while exercising or only because of exercise-induced  $O_2$  and peripheral blood flow changes, and thus requires further research. In general, hypoxic training (low  $PaO_2$ ) stimulates hypoxia-inducible factor-1 (HIF-1) and erythropoietin (EPO) gene followed by an increase in erythrocyte count and hemoglobin concentration, which altogether improves oxygen-carrying capacity and endurance. These proposed benefits of exercising with face masks are heterogeneous, and therefore remain inconclusive [46].

### 3.1.6. Face masks may offer thermogenic effect

N95 and surgical face masks can induce significantly different temperatures and humidity within the microclimates of face masks, which have profound influences on blood circulation and heat exchange mechanisms during rest and exercise. Nielsen et al. (1987) observed that the delivery of air with different temperatures into a face mask was similar to the application of a local thermal stimulus to the skin surface around the mouth, nose, and cheek [47]. Research on face mask usage has shown that the temperature in the

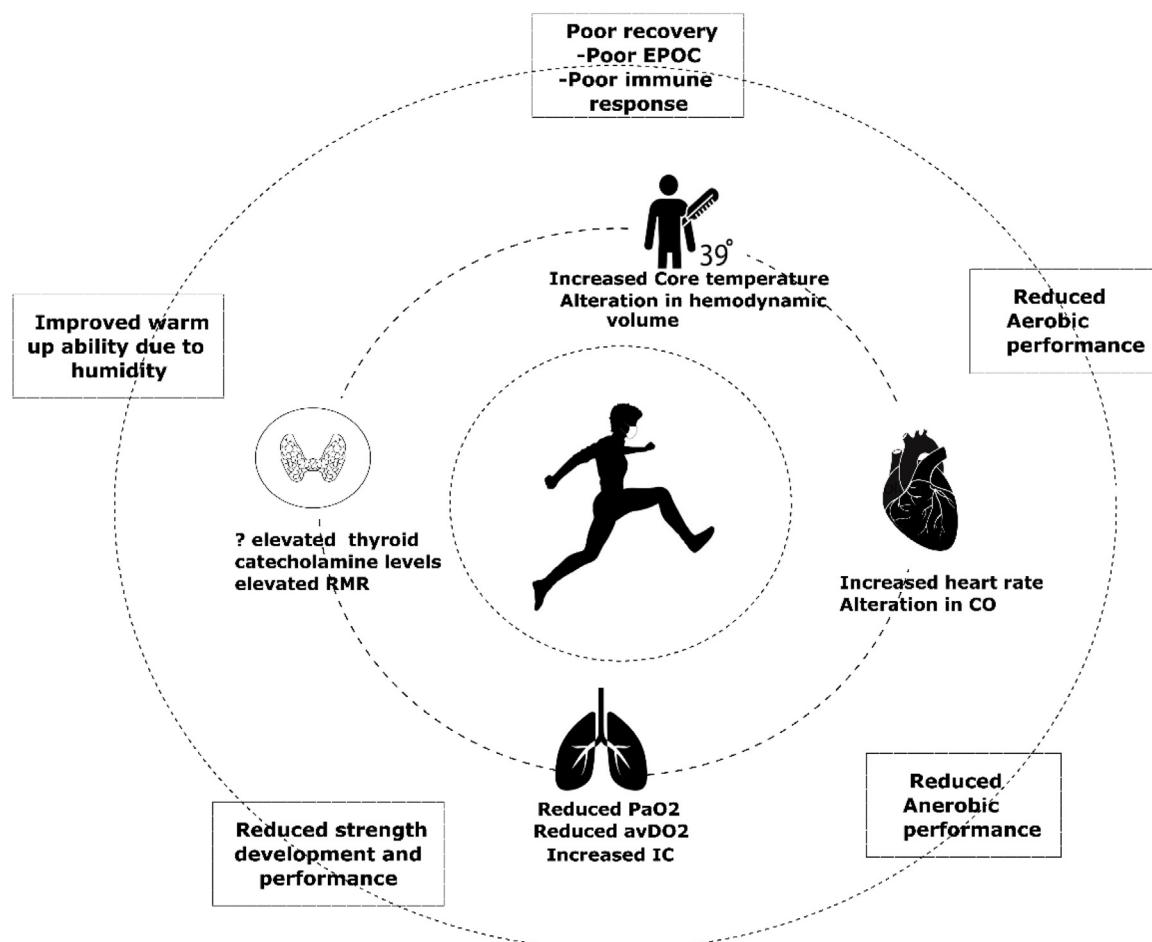
face mask microclimate and heat loss from the respiratory tract was more difficult while wearing an N95 face mask as compared to a surgical mask, and can induce heat stress [48]. However, literature on the effect of cloth masks, buffs, or other types of athletic face mask during training on heat stress, is still scanty.

## 3.2. Perceived negative effects associated with wearing face masks

Apart from the above-mentioned physiological mechanisms that have a potentially therapeutic affect associated with the use of face masks, there are a few perceived risks as well that are worth mentioning.

### 3.2.1. Face masks could tax the respiratory system

During rest and exercise, face masks offer breathing resistance and promote hypoventilation (lower volumes of air breathed and smaller amounts of oxygen used) for the wearer. Prolonged face mask use without break may reduce oxygen availability and may also result in a corresponding decline in the gradient for oxygen transfer between the alveoli and the pulmonary circulation non-clinically [49]. Consequently, this could lead to reduced oxygen saturation in the blood, decreased oxygen transport, and oxygen delivery to the muscles, which could then result in reduced level of endurance capacity and maximum oxygen uptake. Face masks accumulate exhaled carbon dioxide in the voids between the respirator and the face and return it to the respiratory system during the next inspiration. This increased carbon dioxide content in inspiratory air can cause an increase in arterial  $PCO_2$  and a decrease in pH level. It also acts as a respiratory stimulant that can lead to hyperventilation or harder and deeper breathing. Dead volume may also produce discomfort and a performance decrement. Johnson et al. (2000) reported that a typical 350 mL dead volume by



**Figure 3** Postulated physiological effects of exercising with face masks and impact on components of sports performance. ? = remains inconclusive.

a respirator is expected to reduce performance time by 19% at a work rate of 80 to 85% of maximum oxygen consumption ( $\text{VO}_{2\text{max}}$ ) [50].

**3.2.2. Face masks may affect cardiovascular dynamics**  
 The cardiovascular system also responds to acute exercise bouts with face masks, with the intention of reducing the difficulties in oxygen delivery caused by the low  $\text{PO}_2$ . One of the first responses to occur while exercising in hypoxic conditions especially with face masks is an increase in heart rate and thus cardiac output in order to deliver more oxygen to the tissues [51,52]. To compensate for the reduced cardiac filling during rest and exercise, cardiac contractility increases to maintain the stroke volume [51], because shortage of oxygen elevates sympathetic activity and parasympathetic withdrawal, and perhaps temperature effects on the cardiac pacemaker cells [52,53].

### 3.3. Training & performance specific responses with face masks

The impact of face mask use on any training type and performance is related to both the duration and intensity of the event to which the athlete is exposed. An overview of

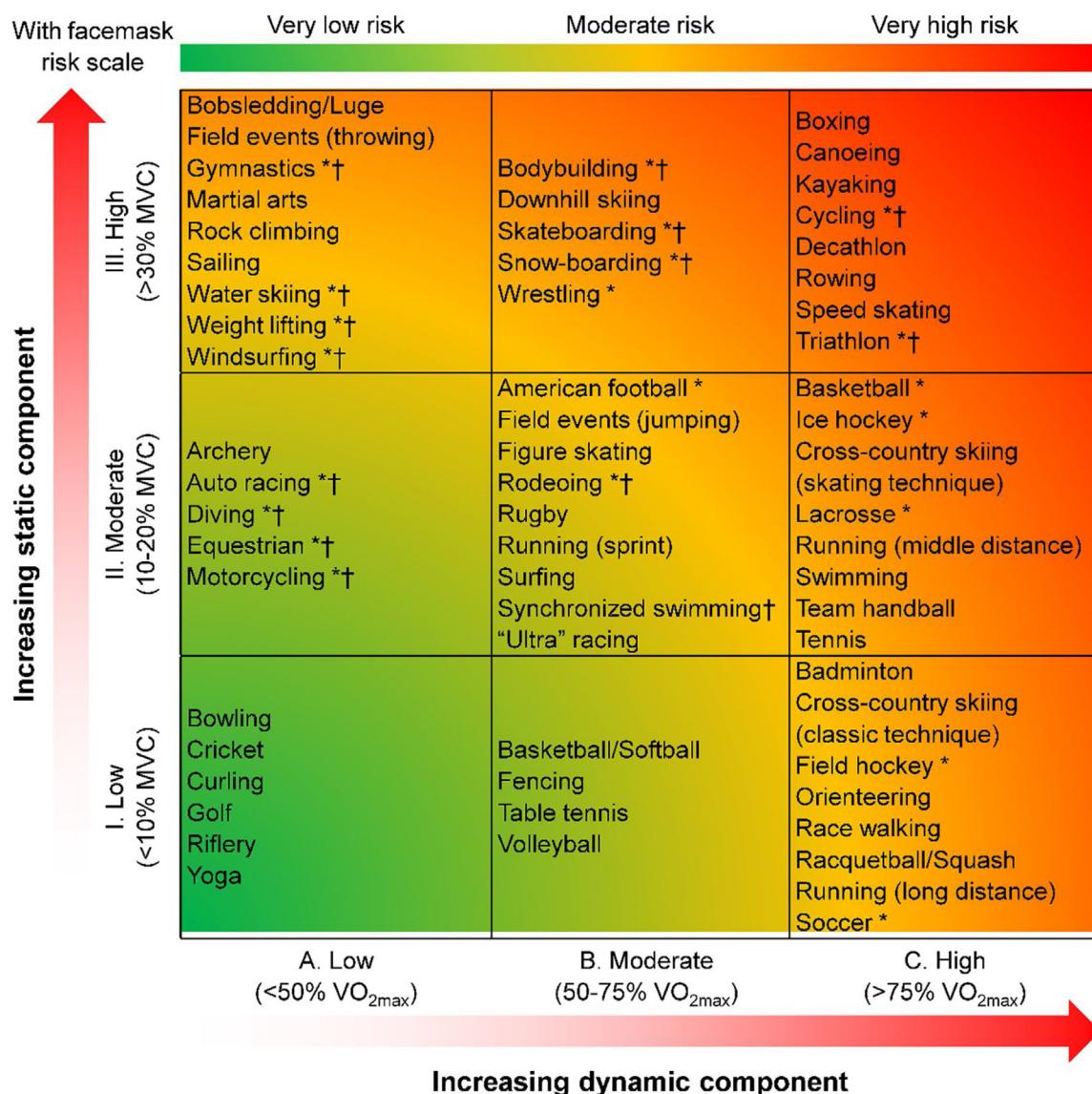
the postulated physiological effects of exercising with face masks and its impact on components of sports performance is depicted in Fig. 3.

#### 3.3.1. Face masks may impact warm-up period

The purpose of warm-up is to reduce muscle stiffness, reduce risk of muscle and tendon injuries, and improve exercise performance by increasing body's core temperature, muscle temperature, and blood flow by reducing the blood viscosity prior to an intense training session or match performance [54,55]. This heating effect allows muscles and tendons to easily and effectively stretch [56]. The use of face masks also increases body temperature and blood flow [47,48,57,58]. Hence, face masks could be considered as a beneficial sports gear for athletes that assists the athletes to achieve warm-up goals faster, and thus augment warm-up outcomes.

#### 3.3.2. Face masks may affect aerobic capacity

Lower  $\text{PO}_2$  and difficulty in breathing is a problem for long-distance events and those events that depend on aerobic performance. Aerobic metabolism and muscle total adenosine pool may decrease, whereas oxygen debt, blood and muscle lactate accumulation, skeletal muscle glycogen utilization, and inosine 5-monophosphate concentration may



**Figure 4** Hypothesized risk matrix for the players to perform a particular sport during competition with the face mask. The increasing dynamic component is defined in terms of the estimated percent of maximal oxygen uptake ( $\text{VO}_{2\text{max}}$ ) achieved and results in an increasing cardiac output. The increasing static component is related to the estimated percent of maximal voluntary contraction (MVC) reached and results in an increasing blood pressure load. 'Very low risk' means that the threat event could be expected to have a negligible adverse effect or almost normal and 'very high risk' means that the threat event could be expected to have multiple severe or catastrophic adverse effect on the body. The lowest risk while training with face mask is shown in green and the highest in red color. \*Danger of bodily collision. †Increased risk if syncope occurs.

all increase during exercise with higher muscle temperatures [59]. The metabolic rate increases in order to perform submaximal exercise, possibly because the rate of adenosine triphosphate utilization to develop a given muscle tension is increased (i.e., increased cross-bridge cycling) as muscle temperature increases. Hence, it is obvious that long duration activities that place considerable demands on oxygen transport and uptake by the tissues are those that are most severely affected by the hypoxic conditions induced by face mask. Guo et al. (2008) also reported that tympanic temperature rose by  $0.2^\circ\text{C}$  for FFR with an exhalation valve (N95 FFR-EV) and  $0.6^\circ\text{C}$  for FFR during staggered treadmill exercise at  $3.2 \text{ km/h}$  for 20 minutes,  $4.6 \text{ km/h}$  for 10 minutes, and

$6.4 \text{ km/h}$  for 10 minutes, interspersed with 10-minute rest periods [58]. With intense or long-duration exercise, heat production from the body and the inability to get rid of the heat form inspiratory air due to face mask use could potentially overwhelm the thermoregulatory system and result in heat stress as well.

**3.3.3. Face masks may affect anaerobic performance**  
During shorter anaerobic performances (few seconds to less than a minute) with face masks, like the 100-m to 800-m track events or throwing events, performance may not be hampered at all. Such activities place minimal demands on the oxygen transport system and aerobic metabolism.

**Table 2** Recommendations for coaches and athletes.

Goals	Challenges	Recommendations
1. Selection of an appropriate face mask	<ul style="list-style-type: none"> <li>• Varying size and fit of the face mask.</li> <li>• Breathing difficulty/suffocation due to dampness of masks [63] as well as hot and humid conditions [48].</li> <li>• Sensory burden [64].</li> <li>• Skin irritation due to fabric [65].</li> <li>• Ocular irritation due to the exhaled air escaping through the top of the mask [66]</li> </ul>	<ul style="list-style-type: none"> <li>• Individualization: proper fit, comfort, game/training demands.</li> <li>• Material: moisture-wicking breathable materials, multi-layered, and lightweight.</li> <li>• Use ergonomic training face masks</li> </ul>
2. Physical distancing	<ul style="list-style-type: none"> <li>• Difficult to maintain 1.5 m physical distance as recommended by WHO especially during dynamic activity [67].</li> <li>• Droplet spread due to athletes' movement in slipstream [67]</li> </ul>	<ul style="list-style-type: none"> <li>• Training in open air.</li> <li>• Enclosed facility/competition: training adaptation with face mask</li> <li>• To avoid slipstream spread (during training): staggered or side-by-side arrangement (Fig. 5)</li> <li>• Close monitoring of athlete symptoms during training/competition.</li> </ul>
3. Monitoring training load	<ul style="list-style-type: none"> <li>• Breathing difficulties/respiratory symptoms can vary depending on exercise intensity and duration</li> </ul>	<ul style="list-style-type: none"> <li>• Reduce exercise intensity or administer complete rest until respiratory symptoms fade away</li> <li>• Increase calorie intake equivalent to RMR increase.</li> <li>• Increase fluid intake to avoid dehydration</li> <li>• Gradually increase exercise intensity.</li> <li>• Regular training.</li> <li>• Acclimatization prior to competition</li> </ul>
4. Hydration and calorie intake	<ul style="list-style-type: none"> <li>• Wearing a mask increases RMR [68].</li> <li>• Wearing face mask can augment sweat rate both at rest and during exercise</li> </ul>	
5. Training adaptation with face mask	<ul style="list-style-type: none"> <li>• Physiological and psychological load with acute exposure</li> </ul>	

RMR: resting metabolic rate.

Instead, most of the energy is provided through the adenosine triphosphate (ATP), phosphocreatine, and glycolytic systems. However, in slightly longer duration events, such as the 1500-m race, rebreathing of hot and humid exhaled air with less O<sub>2</sub> and higher CO<sub>2</sub> percentage may indeed limit performance.

### 3.3.4. Impact on post-exercise recovery responses

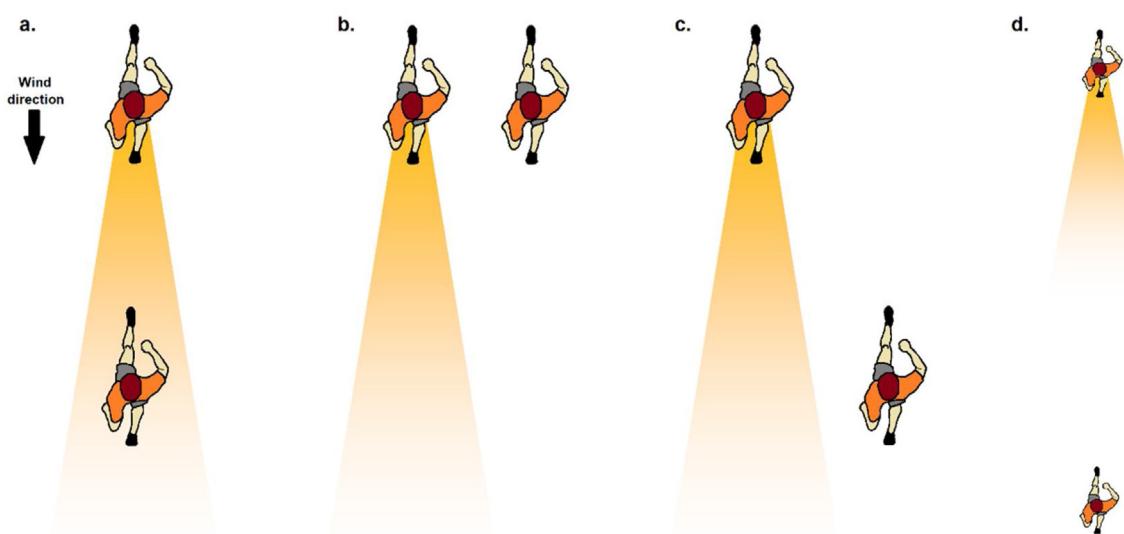
Excess post-exercise oxygen consumption (EPOC) plays a major role in restoration of ATP-PC stores and lactate removal. Analyses of ATP regeneration after fatiguing exercise have demonstrated that re-synthesis of ATP may be slowed in hypoxia [60]. Hence, the recovery after any anaerobic activity or long-term aerobic activity seems to be affected by using face masks. Therefore, although a single bout of exercise may not be affected while performing with a face mask, repetitive anaerobic bouts (such as in football, hockey) may be more fatiguing, resulting in performance decrements.

### 3.4. Hypothesized risk matrix for training with face masks

Mitchell et al. (2005) and later Levine et al. (2015) classified sports into nine classes by the level of intensity (low, moderate, and high) of dynamic and static components, and athletes are required to perform at the level specific to their sport during competition [61,62]. However, the possibility

of the demand of a sport being greater during training than in competition must also be seriously considered. Hence, depending on the training intensity and duration, we hypothesized the athletes' health risk while training with a face mask during this COVID-19 pandemic (Fig. 4). Athletes performing low-intensity short duration exercises or playing games like golf, cricket, yoga, and bowling wearing a face mask could be at a very low risk considering the activity demand and face mask implications. Whereas those who are performing high-intensity exercises for a long time, or those involved in games requiring maximal strength and VO<sub>2</sub>, like boxing, cycling, rowing, canoeing, kayaking with a face mask, could be at very high health risk. As training intensity and/or duration increases with a face mask, the adverse effects and risks will also increase.

Nevertheless, this risk matrix should not be regarded as a rigid classification, rather as a spectrum in which some athletes in the same exercise training group could be placed in different risk categories. Another limitation with this risk matrix is that it does not consider the emotional stress that an athlete experiences while wearing a face mask during training and competitive event, or the effect of environmental factors (like temperature, humidity, altitude). Considering the risks involved with training, the authors have analyzed the problems and provided suitable recommendations for coaches and athletes as depicted in Table 2 (Fig. 5). These may be applicable to most training situations and would enable the coaches to alter training sessions as per the current need of the hour.



**Figure 5** Graphic presentation of droplet exposure when running behind each other (short distance slipstream) (a); side-by-side running (b); staggered arrangement (c); running behind each other (longer distance slipstream) (d).

### 3.5. Practical applications:

Several practical solutions can be advocated when exercising with face masks based on the above putative hypothetical physiological mechanisms. To ameliorate the perceived negative effects associated with the use of face masks during training, the training sessions should be adapted outdoors and in less crowded areas. Even if indoor training is required, adequate ventilated areas with adequate sanitation measures should be adapted. During moderate to vigorous intensity activities, the athletes could be allowed to remove masks, but should be encouraged to maintain social distance equivalent to double the recommended distance. Furthermore, heart rate and saturation should be continuously monitored if the athlete is undergoing any moderate to vigorous stress testing within a closed lab. Adequate sanitation measures and athlete thermal/nasal swab testing for any infection should be regularly adapted in the training centers. Sports coaches and the strength and conditioning specialists should judiciously allow their clients to appropriately don and doff of the face coverings during the training sessions. They must also educate them regarding the pros and cons of wearing the face coverings during exercise and encourage them to promptly report any physiological side effects of hypoxia or hypercapnia such as dizziness, headache associated with wearing the face masks.

### 4. Conclusion

With respect to athletes, face masks have several positive as well as negative implications on physical, physiological as well as psychological well-being and performance. It is primitive to conclude the long-term effects of COVID-19 as the facts are still unknown and research on the same is ongoing. The plausible ill effects that have been identified in this article could enable the sport medicine community to adapt

their training session accordingly, thus reducing the chances of infection and other physiological dysfunctions. During these unusual times, apart from musculoskeletal injury prevention, the sports medicine team would also have to focus on athlete health, and prevention of infection while maximizing their performance.

### Disclosure of interest

The authors declare that they have no competing interest.

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